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16. ABSTRACT

Despite major reductions in the dominant DDT and polychlorinated biphenyls (PCB) input off Los Angeles (California, U.S.A.) in the early 1970s, the levels of these pollutants decreased only slightly from 1972 to 1975 both in surficial bottom sediments and in a flatfish bioindicator (Dover sole, *Microstomus pacificus*) collected near the submarine outfall. In contrast, the DDT and PCB concentrations in surficial sediment, Dover sole, and various sportfish species from the outfall area decreased by about an order of magnitude between 1977 and 1981, when the input rate was relatively low and essentially constant. The total DDT:total PCB ratio in the fish species collected between 1972 and 1981 more closely resembled those in the bottom sediments than those in the wastewater input. Concentrations of these pollutants in the soft tissues of the mussel *Mytilus californianus*, collected intertidally well inshore of the highly contaminated bottom sediments, followed much more closely the decreases in the outfall discharges. These observations suggest that contaminated sediments on the seafloor were the principal (although not necessarily direct) cause of the relatively high and persistent concentrations of DDT and PCB residues in tissues of seafood fishes and invertebrates from the study area 5–7 y after control of the dominant wastewater input. Five of 11 fish species averaged >5 mg kg^{-1} total DDT in their edible tissue, the U.S. Food and Drug Administration (FDA) action guideline for interstate commerce. The highest value, 39 mg kg^{-1}, was found in the muscle of white croaker (*Genyonemus lineatus*), the most popular sportfish caught in southern California. The average concentration of total PCB in this species, 2.8 mg kg^{-1}, also exceeded the 2 mg kg^{-1} FDA action guideline for PCB. In 1980, concentrations in the muscle tissue of white croaker from the outfall study area still averaged 7.6 mg kg^{-1}. The study indicated that residues of the higher-molecular-weight chlorinated hydrocarbons, such as DDT and PCB, can be highly persistent once released to coastal marine ecosystems and that their accumulation in surficial bottom sediments is the most likely cause of this persistence observed in the biota of the discharge zone.

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Chapter 3

EPA/600/D-89/252

Persistence of Chlorinated Hydrocarbon Contamination in a California Marine Ecosystem

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ABSTRACT

Despite major reductions in the dominant DDT and polychlorinated biphenyls (PCB) input off Los Angeles (California, U.S.A.) in the early 1970s, the levels of these pollutants decreased only slightly from 1972 to 1975 both in surficial bottom sediments and in a flatfish bioindicator (Dover sole, *Microstomus pacificus*) collected near the submarine outfall. In contrast, the DDT and PCB concentrations in surficial sediment, Dover sole, and various sportfish species from the outfall area decreased by about an order of magnitude between 1977 and 1981, when the input rate was relatively low and essentially constant. The total DDT:total PCB ratio in the fish species collected between 1972 and 1981 more closely resembled those in the bottom sediments than those in the wastewater input. Concentrations of these pollutants in the soft tissues of the mussel *Mytilus californianus*, collected intertidally well inshore of the highly contaminated bottom sediments, followed much more closely the decreases in the outfall discharges. These observations suggest that contaminated sediments on the seafloor were the principal (although

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not necessarily direct) cause of the relatively high and persistent concentrations of DDT and PCB residues in tissues of seafood fishes and invertebrates from the study area 5–7 y after control of the dominant wastewater input. Five of 11 fish species averaged >5 mg kg^{-1} total DDT in their edible tissue, the U.S. Food and Drug Administration (FDA) action guideline for interstate commerce. The highest value, 39 mg kg^{-1}, was found in the muscle of white croaker (*Genyonemus lineatus*), the most popular sportfish caught in southern California. The average concentration of total PCB in this species, 2.8 mg kg^{-1}, also exceeded the 2 mg kg^{-1} FDA action guideline for PCB. In 1980, concentrations in the muscle tissue of white croaker from the outfall study area still averaged 7.6 mg kg^{-1}. The study indicated that residues of the higher-molecular-weight chlorinated hydrocarbons, such as DDT and PCB, can be highly persistent once released to coastal marine ecosystems and that their accumulation in surficial bottom sediments is the most likely cause of this persistence observed in the biota of the discharge zone.

3.1. INTRODUCTION

Chlorinated hydrocarbons, such as the pesticide DDT and the industrially important polychlorinated biphenyls (PCB), are probably the most serious environmental contaminants studied over the past several decades (Risebrough, 1969; DeLong et al., 1973; U.S. National Academy of Sciences, 1975; Young et al., 1983). Concern over the unrestricted release of these higher-molecular-weight synthetic organic compounds increased in the late 1960s, and programs were developed to reduce their emissions and to monitor ecosystems exposed to such discharges. One benefit of the long-term monitoring programs has been an increased understanding of the rates at which different components of particular ecosystems will recover chemically or biologically from a major environmental stress after that stress has been removed or greatly reduced. This chapter presents results obtained from a 10-y study of chlorinated hydrocarbons in the vicinity of one of the nation's largest submarine outfall systems, which has been a principal source of DDT and PCB residues to the coastal waters of southern California.

3.2. STUDY AREA

The Joint Water Pollution Control Plant (JWPCP) of the Los Angeles County Sanitation Districts (LACSD) releases municipal wastewater through a submarine outfall system at a depth of ~60 m off Whites Point, Palos Verdes Peninsula, in the Southern California Bight (Fig. 3.1). Industrial discharges to the JWPCP sewer have been a major source of metals and synthetic and petroleum hydrocarbons to the coastal waters, causing high concentrations of these materials in the bottom sediments (Young et al., 1975a; Young et al., 1978). Although PCB are ubiquitous contaminants with numerous individual sources, the predominant input of DDT to the wastewater system arose from one of the world's largest manufacturers of the pesticide, Montrose Chemical Co., in Los Angeles County (Carry and Redner, 1970; Anderson, 1983; Young and Heesen, 1978).

Large quantities of DDT residues were released for two decades, and a survey in 1972 (Young et al., 1976) revealed that ~200 metric tons (t) of these residues had accumulated in the upper 30 cm of bottom sediments in a 50-km^2 area off the Palos Verdes Peninsula (Fig. 3.1). Gradients of 2–4 orders of magnitude existed between the boundaries of the bight and the JWPCP discharge zone for total DDT concentrations in bottom sediments, intertidal mussels, flatfish, and other benthic organisms (Risebrough, 1969; Burnett, 1971; Duke and Wilson, 1971; DeLong et al., 1973; McGregor, 1974; Risebrough et al., 1974; Young et al., 1975b; McDermott et al., 1976; Young et al., 1978). The pesticide was also accumulated by pelagic organisms, leading to at least one seizure of a commercial fish shipment (white croaker, *Genyonemus linea-*

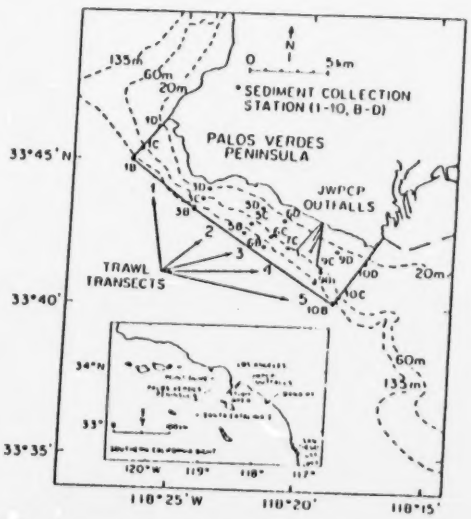

Figure 3.1. The study area (bordered by solid line) within the JWPCP outfall monitoring zone. Royal Palm Beach is located at the base of the outfall system.

tus) for tissue residues above the U.S. Food and Drug Administration's (FDA) action guideline of 5 mg kg^{-1} (wet wt). Reproduction of the brown pelican (*Pelicanus occidentalis*) off southern California was severely reduced owing to eggshell thinning caused by excessive levels in tissue of total DDT (DDT plus the primary metabolites DDE and DDD), which were accumulated through the plankton–anchovy–marine–bird food web (Anderson et al., 1975).

Release of DDT wastes from the Montrose Chemical Co. to the JWPCP sewer was terminated in the spring of 1970 (Anderson, 1973). Nevertheless, ~22 t of DDT residues were discharged in 1971 through the JWPCP submarine outfall system (Young and Heesen, 1978). In 1971, a survey by the LACSD revealed ~60 t of total DDT in sediments that had settled in a 200-m section of a wastewater main downstream from the pesticide manufacturer. These highly contaminated sewer sediments appear to account for the large discharge of DDT residues monitored by the LACSD during 1971.

3.3. METHODS

In 1971, a long-term monitoring program was initiated for chlorinated hydrocarbons in wastewater, bottom sediments, flatfish, and intertidal mussels from the JWPCP outfall study area off the Palos Verdes Peninsula (Fig. 3.1). Duplicate sets of flow-weighted, composite week-long samples of JWPCP effluent were collected during summer and winter of each year, preserved without filtration by addition of pesticide-grade hexane, and analyzed in the laboratories of both the LACSD and the Southern California Coastal Water Research Project (SCCWRP). The major constituents measured were *total DDT* (expressed as the sum of the *p,p'* and *o,p'* isomers of DDT, DDE, and DDD) and *total PCB* (expressed as the sum of PCB 1242 and PCB 1254). Very satisfactory agreement (generally within 20%) was obtained between the two laboratories for concentrations of total DDT in the JWPCP effluent (Young et al., 1976); the monthly DDT values from the LACSD's monitoring program were adopted for this study. Consistent agreement was not obtained for PCB analyses by the two programs, and the values for PCB concentrations reported here are the average of the four values per year obtained in the SCCWRP laboratory.

Bottom sediments were collected by a Phleger gravity corer or Shipek grab sampler from 19 benthic stations (Fig. 3.1) within the JWPCP outfall study area during the summer of 1972 and the summer of 1975. The sediments were then analyzed at SCCWRP for DDT and PCB residues in the top 5-cm layer (Young et al., 1977). The top 2-cm layer of sediment from several of these same stations was sampled during the summer of 1977 and the spring of 1981 by using a modified Van Veen grab sampler (Word, 1976). The variations in sediment samplers and layer thicknesses used in this study resulted from modifications made in the monitoring programs. Although systematic differences caused by the changes in sampling methods were not observed, to minimize bias the 5-cm layer results (for 1972 and 1975) and the 2-cm layer results (for 1977 and 1981) were compared independently. Stull et al. (Chapter 2) described in detail the vertical distributions of chlorinated hydrocarbons and other contaminants, which were measured in sediment core samples, and corresponding estimated sedimentation rates, which were obtained from several stations in the JWPCP outfall study area.

Tissues from a number of different species of organisms collected from various sites near the outfall were analyzed for DDT and PCB residues during this same period. Specimens of Dover sole (*Microstomus pacificus*), with standard lengths generally ranging from 130 mm to 200 mm, were analyzed for DDT and PCB residues in the muscle tissue (Young et al., 1977). Composite samples of the undepurated soft tissues from five specimens of the intertidal mussel *Mytilus californianus* which were 4–6 cm in length, were obtained quarterly (February, May, August, and November) most years during 1971–1981 from Royal Palm Beach at the base of the JWPCP outfalls (Fig. 3.1). Because of the extended period of freezer storage for some of these samples, all were freeze-dried before analysis, and the concentrations were converted to a wet-weight basis by using an average value of 83% moisture determined for fresh specimens. (Tests on wet and freeze-dried aliquots of fresh mussel samples showed no detectable differences in total DDT or total PCB concentrations.) Finally, 17 species of seafood fishes and invertebrates, collected between the spring of 1975 and the spring of 1977 from the outfall study area and at southern California island (Santa Catalina) or coastal (Dana Point) control stations (Fig. 3.1), were analyzed similarly. Sample preparation and analytical procedures used at SCCWRP have been described by Young et al. (1976) and Hu et al. (1980).

3.4. RESULTS AND DISCUSSION

The controls placed on the release of chlorinated hydrocarbons into the JWPCP wastewater collection system during the early 1970s caused a large reduction in the annual discharges of DDT and PCB residues via the submarine outfall system

off Palos Verdes Peninsula. Between 1972 and 1975, the estimated emissions of total DDT and total PCB were reduced by approximate factors of 6 and more than 18, respectively (Table 3.1). However, the median concentrations of total DDT and PCB 1254 (the only PCB residue measured) in the surficial sediments only decreased over this period by factors of 1.6 and 1.2, respectively (Table 3.2). The corresponding 1972–1975 decrease factors for the Dover sole that were trawled from the study area were 1.5 and 1.9 (Table 3.3), respectively. By 1977, the major reductions in the JWPCP discharges of DDT and PCB residues had already occurred, and over the next 4 y the decrease factors for these contaminants were only 1.8 and 0.8, respectively (Table 3.1). In contrast, the 1977–1981 decrease factors obtained for the median concentrations of total DDT and total PCB measured in surficial sediments from three stations in the JWPCP study area in 1977 and 1981 were ~9 and 12, respectively (Table 3.2). The corresponding decrease factors for these residues in the Dover sole collected from this area were 9 and 15, respectively (Table 3.3).

Thus, over the study period the concentrations of total DDT and total PCB in muscle tissue of Dover sole collected from the JWPCP outfall study area appear to have more closely followed the levels of contaminants measured in the surficial sediments than the levels of contaminants measured in the effluent discharges (Fig. 3.2 and 3.3; Table 3.4). In contrast, the concentrations of these chlorinated hydrocarbons in the soft tissue of the intertidal California mussel more closely followed the annual discharges from the outfalls (Fig. 3.2; Fig. 3.3). This filter-feeding organism occupies a hard substrate in a high-energy, non-depositional environment; thus, it is much more likely to be exposed to recently released effluent particulate material than to the historical deposits of the more highly contaminated particulate material that had been incorporated into the fine-grained bottom sediments inhabited by the Dover sole.

Table 3.1. Annual Emissions of JWPCP Municipal Wastewater, Total DDT, and Total PCB Discharged off Palos Verdes Peninsula from 1971 to 1981

Year	Flow (10^{11} liter y^{-1})	Total DDT (kg y^{-1})	Total PCB (kg y^{-1})
1971	5.13	21,600	—[a]
1972	4.84	6,300	≥11,600
1973	4.96	3,720	2,670
1974	4.78	1,440	1,270
1975	4.71	1,080	650
1976	4.88	850	1,320
1977	4.63	730	310
1978	4.78	970	150
1979	5.07	640	640
1980	5.17	540	390
1981	5.03	420	270

[a]Dash indicates no data.

Table 3.2. Median and Mean Concentrations of Measurable DDT and PCB Residues in Surficial Sediments from the JWPCP Outfall Study Area from 1972 to 1975 and 1977 to 1981[a]

Period	Total DDT (mg kg^{-1} ±1 standard error)		PCB Residue[b] (mg kg^{-1} ±1 standard error)	
	Median	Mean	Median	Mean
Monitoring Grid[c]				
1972	19	66 ± 16	1.0	4.0 ± 1.0
1975	12	41 ± 9.6	0.81	2.4 ± 0.64
1972:1975	1.6	1.6	1.2	1.7
Diffuser Transect[d]				
1977	49	86 ± 45	3.8	5.8 ± 2.6
1981	5.6	6.5 ± 1.1	0.33	0.34 ± 0.14
1977:1981	8.8	13	12	17

[a]Surficial sediment samples were 0–5 cm from 1972 to 1975 and 0–2 cm from 1977 to 1981.
[b]From 1972 to 1975 PCB 1254 was analyzed. From 1977 to 1981 total PCB were analyzed.
[c]The monitoring grid is 17–19 stations around discharge in 30–150 m water depth.
[d]The diffuser transect was three stations (3C, 5C, and 7C) downcurrent of the discharge in 60 m water depth.

The specimens of Dover sole analyzed during this study generally fell within the size range of 130–200 mm standard length, corresponding approximately to age classes II–IV (Mearns and Harris, 1975). In particular, the standard length of the specimens collected in May 1977 (whose contamination levels were similar to those collected in May 1972) averaged ~140 mm (with an average whole-body weight of ~40 g) and thus probably had inhabited the outfall study area for no more than 2 y. These specimens, therefore, must have entered the outfall study area several years after the major reduction in the outfall loading of DDT and PCB residues; they could not have accumulated their high levels of contaminants during the high discharge period and simply retained the residues in their tissues. The June 1980 and June 1981 specimens were somewhat smaller than were the May 1977 specimens (average standard length of ~130 mm and whole-body weight of ~30 g). We have not observed significant relationships between fish size and age and tissue concentra-

Table 3.3. Median and Mean Concentrations of Total DDT and Total PCB in Muscle Tissue of Dover Sole (*Microstomus pacificus*) Trawled from the JWPCP Outfall Monitoring Zone from 1972 to 1981

Period	*n*	Total DDT [mg kg^{-1} (wet wt) ±1 standard error]		Total PCB [mg kg^{-1} (wet wt) ±1 standard error]	
		Median	Mean	Median	Mean
May 1972	21	17	26 ± 5.3	2.1	2.3 ± 0.36
Dec 1973	9	18	16 ± 2.4	1.9	2.0 ± 0.23
May 1974	20	13	15 ± 2.4	1.5	1.5 ± 0.19
Feb 1975	10	11	25 ± 10	1.1	1.9 ± 0.67
Nov 1976	24	16	17 ± 2.2	1.2	1.1 ± 0.14
May 1977	25	20	26 ± 5.2	1.4	1.8 ± 0.4
Jun 1980	17	2.7	3.6 ± 0.77	0.093	0.14 ± 0.03
Jun 1981	4*	2.3	2.5 ± 0.06	0.093	0.13 ± 0.03

*Composite samples of 18 ± 2 individuals each.

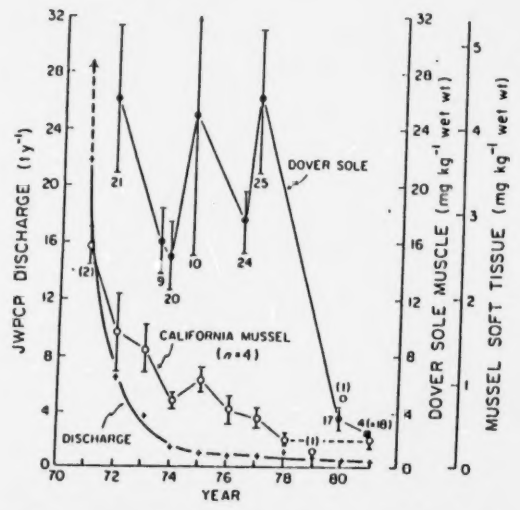

Figure 3.2. Annual discharge of total DDT via the JWPCP outfalls (t), compared with average concentrations (±1 standard error) of total DDT in muscle tissue of Dover sole (*Microstomus pacificus*) (solid circle) and whole soft tissues of the California mussel (*Mytilus californianus*) (hollow circle; $n = 4$) from the outfall study area, 1971–1981.

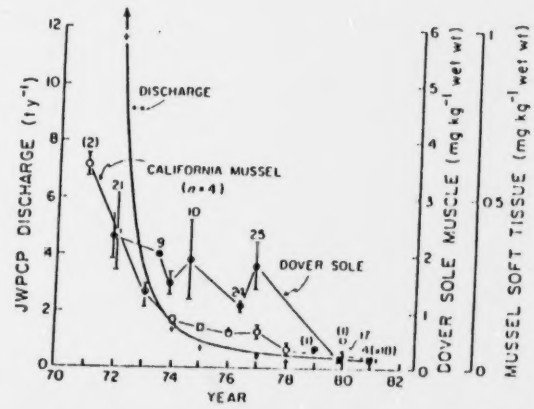

Figure 3.3. Annual discharge of total PCB via the JWPCP outfalls (t), compared with average concentrations (± 1 standard error) of total PCB in muscle tissue of Dover sole (*Microstomus pacificus*) (solid circle) and in soft tissues of the California mussel (*Mytilus californianus*) (hollow circle; $n = 4$) from the outfall study area, 1971–1981.

tion of DDT or PCB residues, however, that could account for the order-of-magnitude concentration reductions from 1977 to 1980–1981.

The foregoing observations suggest that the lag in decline of DDT and PCB in Dover sole after the significant loading reductions in the early 1970s can be attributed to the persistence of chlorinated hydrocarbon contamination in the surficial sediment environment (sediment, interstitial water, and/or infaunal prey). The most likely routes of such hypothesized uptake from this environment are direct partitioning from contaminated interstitial water and/or consumption of contaminated benthic organisms.

The large reservoir of DDT and PCB residues contained in the bottom sediments off Palos Verdes Peninsula during the mid-1970s was probably at least indirectly responsible also for the relatively high concentrations of these synthetic or-

Table 3.4. Median and Mean Concentrations of Total DDT and Total PCB in Whole Soft Tissue of California Mussels (*Mytilus californianus*) Collected Quarterly from Royal Palm Beach at the Base of the JWPCP Outfalls, 1971–1981*

		Total DDT		Total PCB	
Period	*n*	Median	Mean	Median	Mean
1971	2	2.7	2.7 ± 0.22	0.61	0.61 ± 0.034
1972	4	1.2	1.6 ± 0.48	0.31	0.41 ± 0.12
1973	4	1.5	1.4 ± 0.29	0.27	0.22 ± 0.034
1974	4	0.75	0.82 ± 0.10	0.15	0.15 ± 0.008
1975	4	1.0	1.1 ± 0.15	0.12	0.12 ± 0.012
1976	4	0.73	0.71 ± 0.19	0.11	0.11 ± 0.019
1977	4	0.60	0.61 ± 0.12	0.10	0.11 ± 0.022
1978	4	0.36	0.34 ± 0.05	0.054	0.054 ± 0.012
1979	1	0.20	0.20	0.060	0.060
1980	1	0.87	0.87	0.087	0.087
1981	4	0.32	0.34 ± 0.10	0.034	0.037 ± 0.003

*Concentrations expressed as mg kg^{-1} wet wt ± 1 standard error. Converted from a freeze-dry weight basis using an average value of 83% moisture determined for fresh specimens.

ganic compounds measured in the edible tissue of other seafood organisms collected during 1975–1977 from the JWPCP study area (Table 3.5). Average levels of DDT residues in 5 of the 11 fish species that were investigated exceeded the FDA action guideline (5 mg kg^{-1}). White croaker exhibited the highest mean total DDT concentration (39 mg kg^{-1}) and the highest mean total PCB concentration (2.8 mg kg^{-1}) which exceeded the 2 mg kg^{-1} limit for polychlorinated biphenyls in seafood (U.S. FDA, 1977, 1984). According to a 1978 sportfishing survey by the California Department of Fish and Game, one in three fish caught in southern California was a white croaker, making it the most popular sportfish there (Gossett et al., 1983). Of the 17 seafood species collected off the Palos Verdes Peninsula, 11 averaged >1 mg kg^{-1} total DDT in their edible tissue (Table 3.5). These observations are consistent with those reported previously for total DDT in muscle tissue of Dover sole, black perch, and kelp bass collected off the peninsula between 1970 and 1977 (Smokler et al., 1979).

Liver samples from five fish species were also analyzed, and all contained much higher concentrations of chlorinated hydrocarbons than did the corresponding muscle samples (Table 3.5). Average concentrations (± standard error) of total DDT in the livers of Pacific sanddab (n = 2), white croaker (n = 10), scorpionfish (n = 2), sablefish (n = 6), and Bocaccio (n = 7) from the outfall zone were 930 ± 170, 130 ± 48, 115 ± 2, 63 ± 10, and 32 ± 17 mg kg^{-1}, respectively; corresponding values for total PCB were 51 ± 5, 7.6 ± 2.0, 12 ± 7, 0.28 ± 0.08, and 4.1 ± 1.3 mg kg^{-1}. In comparison, multiple analyses (n = 6) of a homogenate of liver tissue from six Dover sole collected during November 1976 from the study area yielded averages of 240 ± 34 mg kg^{-1} total DDT and 18 ± 3 mg kg^{-1} total PCB (Young and Heesen, 1978).

Five sportfishes (white croaker, scorpionfish, kelp bass, Bocaccio, and bonito) were collected from the JWPCP outfall study area during 1980 as part of a seafood contamination survey (H. Puffer, personal communication), and samples were analyzed at SCCWRP. The average contaminant concentrations in these muscle tissue samples collected in 1980 were lower by factors of ~5 and 7 for total DDT and PCB, respectively, than were the corresponding values obtained in the 1975–1977 seafood survey (Table 3.5). These values are of the same order as the 1977–1981 decrease factors for total DDT (9) and total PCB (12) in sediments (Table 3.2). This observation supports the hypothesis that the DDT and PCB contamination of the seafood fishes from the study area during 1975–1980 was maintained by the chlorinated hydrocarbon contamination of the surficial sediment environment there.

Despite the major reductions in levels of chlorinated hydrocarbons in the sediments, Dover sole, and sportfishes collected off the Palos Verdes Peninsula after 1977, very high levels of DDT residues (>5 mg kg^{-1}) remained in muscle tissue of the white croaker collected off the peninsula in 1980. The mean and standard error values for total DDT were 7.6 ± 1.6 mg kg^{-1}; corresponding values for total PCB were 0.38 ± 0.05 mg kg^{-1} (Gossett et al., 1983). Thus, more than 10 y after the predominant industrial source was removed from the JWPCP wastewater collection system, levels of DDT and its

Table 3.5. Mean Concentration (± standard error) of Total DDT and Total PCB in Muscle Tissue of Seafood Organisms from the JWPCP Outfall Study Area and Southern California Control Regions from 1975 to 1977[a]

Organism	Outfall Zone			Island Control Zone		
	n	Total DDT [mg kg^{-1} (wet wt)]	Total PCB [mg kg^{-1} (wet wt)]	*n*	Total DDT [mg kg^{-1} (wet wt)]	Total PCB [mg kg^{-1} (wet wt)]
Fishes						
White croaker (*Genyonemus lineatus*)	10	39 ± 18	2.8 ± 1.0	—	—	—
Dover sole (*Microstomus pacificus*)[b]	35	26 ± 5	1.8 ± 0.3	11	0.029 ± 0.003	0.011 ± 0.002
Pacific sanddab (*Citharichthys sordidus*)[b]	13	6.2 ± 0.7	0.53 ± 0.07	10	0.17 ± 0.03	0.026 ± 0.006
Sablefish (*Anoplopoma fimbria*)[c]	6	5.6 ± 1.7	0.28 ± 0.08	—	—	—
Black perch (*Embiotoca jacksoni*)[d]	26	5.4 ± 0.6	0.89 ± 0.12	8	0.04 ± 0.02	—
Scorpionfish (*Scorpaena guttata*)	4	3.6 ± 0.7	0.57 ± 0.14	3	0.097 ± 0.033	0.043 ± 0.017
Queenfish (*Seriphus politus*)[e]	6	3.3 ± 0.9	0.72 ± 0.16	—	—	—
Kelp bass (*Paralabrax* clathratus)	6	1.6 ± 0.3	0.30 ± 0.10	3	0.030 ± 0.014	0.033 ± 0.010
Bocaccio (*Sebastes paucispinis*)	7	1.1 ± 0.5	0.15 ± 0.04	—	—	—
Bonito (*Sarda chilinesis*)[b]	3	0.83 ± 0.27	0.31 ± 0.10	3	1.1 ± 0.4	0.39 ± 0.12
Anchovy (*Engraulis mordax*)	5	0.30 ± 0.05	0.07 ± 0.02	3	0.24 ± 0.15	0.036 ± 0.010
Invertebrates						
Sea urchin (*Strongylocentrotus franciscanus*)[f]	35	4.5 ± 0.6	1.2 ± 0.3	—	—	—
Crab (*Cancer anthonyi*)[b]	5	1.5 ± 0.2	0.37 ± 0.16	3	0.004 ± 0.002	0.032 ± 0.006
Mussel (*Mytilus californianus*)[g]	4	0.84 ± 0.16	0.15 ± 0.02	4	0.12 ± 0.007	0.056 ± 0.006
Lobster (*Panulirus interruptus*)	5	0.56 ± 0.26	0.10 ± 0.05	3	0.003 ± 0.001	0.010 ± 0.004
Scallop (*Hinnites giganteus*)	9	0.15 ± 0.01	0.014 ± 0.001	10	0.040 ± 0.017	0.004 ± 0.002
Abalone (*Haliotis cracherodii*)	5	0.001 ± 0.0003	0.08 ± 0.06	3	0.0001 ± 0.0001	0.023 ± 0.011

[a]Dash indicates no data.
[b]Control specimens from Dana Point.
[c]Collected March 1978.
[d]D. Hotchkiss (personal communication).
[e]Based on a measured muscle:whole body ratio of mean concentrations (±1 standard error) of 0.8 ± 0.2.
[f]Gonadal tissue of samples collected March 1979. J. Meistrell (personal communication).
[g]Based on analysis of duplicate composites of fresh soft tissue obtained June 1974 and January 1976 (both outfall and control zones).

residues still exceeded the FDA action guideline in one popular sportfish collected from the JWPCP outfall study area.

The correlation coefficients listed in Table 3.6 show that, during this study, the mean concentrations of total DDT and total PCB were strongly associated in every medium analyzed. However, the average ratios (±1 standard error) of mean total DDT to mean total PCB concentrations are significantly different for the JWPCP final effluent (2.0 ± 0.6) and surficial sediments (16.9 ± 0.9). The similarity of the average for surficial sediments to that obtained for muscle tissue from Dover sole (14.7 ± 2.0) provides further evidence that concentrations of DDT and PCB residues in the Dover sole were controlled principally by contaminant concentrations in the surficial sediments rather than in the discharged wastewater. A laboratory study of chlorinated hydrocarbon uptake by Dover sole that were fed an uncontaminated diet and maintained in sediment both from the outfall zone and from a

Table 3.6. Median and Average Ratio of Mean Total DDT and Mean Total PCB Values and Corresponding Correlation Coefficient (r) Obtained for the Various Types of Samples Collected During 1971–1981 from the JWPCP Outfall Study Area

Sample Type	n	DDT and PCB		r	Significance[b]
		Median	Average[a]		
Wastewater (effluent)	9	1.4	2.0 ± 0.6	0.903	$p < 0.001$
Sediment (surficial)	4	16.8	16.9 ± 0.9	0.996	$p < 0.01$
Dover sole (muscle)	8	13.8	14.7 ± 2.0	0.912	$p < 0.01$
Seafood fishes (muscle)	11	6.3	8.8 ± 1.6	0.973	$p < 0.001$
Seafood invertebrates (edible tissue)	6	4.8	5.0 ± 1.4	0.993	$p < 0.001$
Mussels (soft tissues)	11	6.2	6.6 ± 0.6	0.965	$p < 0.001$

[a]Average ±1 standard error.
[b]$p < 0.01$: very significant; $p < 0.001$: highly significant.

control zone supports this hypothesis (Sherwood, 1976; Sherwood and Mearns, 1977). The average DDT:PCB ratio in muscle tissue of the 11 fishes collected in the 1975–1977 seafood survey was substantially smaller (8.8 ± 1.6) but still agreed more closely with that for the surficial sediment than for the wastewater. The average DDT:PCB ratio for the six seafood invertebrate species, which were hand collected well inshore of the most highly contaminated bottom sediments, was 5.0 ± 1.4 (Table 3.6).

Examination of the DDT:PCB ratios obtained from the mean concentrations (Table 3.5) from the seafood survey provides further insight on this topic. Considering the six fishes for which specimens were obtained from both the outfall and island control zones, the average ratio for the outfall zone specimens was 7.4 (±2.0), twice the value of 3.6 (±1.1) obtained for the control zone specimens. A similar result is obtained for the five seafood invertebrates collected from both zones, where the respective average DDT:PCB ratios were 5.2 (±1.7) and 2.5 (±1.9). These observations are consistent with the fact that discharges from the JWPCP outfall system have been the predominant source of DDT wastes to the southern California Bight, while PCB inputs are distributed more generally throughout this region (Young and Heesen, 1978). Thus, the DDT:PCB ratio would be expected to decrease in environmental samples with increasing distance from the outfall plume.

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